A REAL-TIME GEOSENSING NETWORK FOR SPATIAL MODELING OF ROCKBURST FIELDS IN A DEEP HARD ROCK ENVIRONMENT

A rockburst is a violent failure of a mine opening and is usually associated with deep mining operations. The objective of this research is to detect and reduce rockburst hazards by studying seismic energy release, geostructural data including mine opening closure rates, and *in situ* stress measurements. Little progress has been made in determining mechanisms of rockbursts, but improved methods of support have been developed that can prevent damage from minor events and materially reduce the intensity of damage caused by larger events. If deep mining is to continue, a better understanding of the failure mechanism is necessary, particularly in respect to the interaction between mining-induced stresses and the tectonic environment. This research will study seismic events and deformation around active mine openings to forecast and model the change in stress and seismic levels over time to aid our understanding of the mechanisms of rockbursting.

Parallel investigations into a promising new technique for determining subsurface stresses using a down-hole orbital vibrator (DHOV) will also be made. Within the mining industry, prediction of rockburst potential and the elastic parameters that control it affect: 1) cost and efficiency of production by increase of overall energy used or volume of waste material mined; 2) resource characterization in terms of how the rock volume will behave relative to its elastic anisotropy and, ultimately, its mineability, and; 3) safe extraction in terms of knowing the potential of rockbursts in an area to be mined.

Statement of the Problem and Technology Concept

A phenomenon that occurs during underground mining is the rapid release of elastic strain energy. Within the industry, this is known as a rockburst. The probability of a rockburst increases with the depth, extent, and intensity of mining activity, but, to date, the behavior of rockbursts does not appear to follow any known pattern. Resulting failures are often catastrophic, with large volumes of rock being displaced. Rockburst hazards are very serious, sometimes causing injuries and deaths. The costs associated with clean-up, rock support, and lost production time are significant. It is well known that rockbursting is closely related to such factors as mining techniques and geometry, geological structure and local tectonics, and interactions between lithostatic, mining, and tectonic stresses. Underground mines in the Coeur d’Alene district of Northern Idaho reached sufficient depths to create rockbursts in the 1930’s. The first rockburst fatalities occurred in the 1940’s, with casualties occurring almost yearly in the district during that time. Problems associated with rockbursting have increased the cost of producing ore up to 18% and individual bursts have cost over one million dollars in lost production and repairs. The primary limitation in studying the failure mechanism is a lack of quantitative measurements of in-mine displacement during large rockbursts. Numerous investigators have accumulated data on mine damage over the years. However, precision measurements of co-seismic strain are still lacking. For many years, earthquake seismologists have been employing geodetic strain measurements of co-seismic displacements in mines. Developing a thorough understanding of the failure mechanism is the first step toward the eventual mitigation and prediction of rockburst failures. The purpose of this research project is to predict rock mass characterization with respect to seismic energy release, geostructural data including mine opening closure rates, and *in situ* stress measurements. The successful outcome of the project will be the ability to forecast stress levels and the ability to acquire geostructure data for predicting *in-situ* stress as related to rockbursting in mines.

Objective

The objective of this research is to detect and reduce rockburst hazards by studying seismic energy releases, geostructural data including mine-opening closure rates, and *in-situ* stress measurements. The technology to be developed through this work will be a real-time geosensing network, spatial and temporal models for utilization in the identification and prediction of high *in-situ* stress fields prior to their failure, and the evaluation of orbital vibrator technology for sensing/ mapping fractures in the rocks to be mined. The vibrator data will be used in conjunction with data from the geosensing network to provide a more complete geologic representation of actual stress conditions in the mine for input into the models. Academic partners will perform work related to the development of the real-time geosensing network and spatial/temporal models. Industrial support for tasks associated with this portion of the project will provide in-kind engineering support for the installation of the geosensing network as well as the provision of diamond drilling services. Scientists at the Idaho National Engineering and Environmental Laboratory will perform the evaluation of orbital vibrator technology. Industry partners will provide both the orbital vibrator and in-kind engineering support in preparation of the tool for the field evaluation tests. Another academic partner will provide the wireline reel required for running the tool. The project team has extensive experience directly related to this work. INEEL brings extensive experience in applied engineering and the development of sensors used for geophysical measurements.

Acoustic Emission Studies: The objective of the study will be accomplished, in part, by using acoustic emission (AE) techniques. These techniques have the advantage of being non-intrusive, robust, economical, and relatively maintenance free. To identify rock mass characteristics, a neural network (an intelligent computing system for distinguishing AE signals and making recommendations to control the drilling system for the drilled objects) will also be used to develop the artificial expert system. This system will contribute to both enhancing the understanding of the geological conditions and the goal of enhanced mine safety and productivity.

Orbital Source Evaluation: In the 1980's, it was discovered that an orbital vibrator couples strongly through wellbore liquids to the surrounding formation without clamping the source to the sidewall, and that the source effectively generates strong shear and compression waves in a 360° horizontal pattern about a wellbore. Orbital sources, instrumented internally with geophones, provide source signals used in data processing. Monitoring of the internal motion detectors led to the discovery that both shape and amplitude of the source's orbit are influenced by the type of formation surrounding the source, even if the wellbore is lined with casing. The highly effective coupling between the source and the wellbore, through the wellbore liquid, causes this phenomenon, and serves as a tight feedback path. Thus, the orbital source, wellbore liquid, and surrounding formation all become a closely coupled dynamic system with a driving point impedance that is a function of source depth and frequency. The orbital source's potential for use as a logging tool is based on the observed fact that the source motion is modified by the elastic properties of the formations surrounding the wellbore. We also believe the orbital vibrator has potential for sensing formation conditions not only near the wellbore, but also, at significant radial distances from the well. The effective distance should be a function of the sonic wavelength produced by the source. At low frequencies, seismic wavelengths are relatively long and measurement depth should be greatest. At increasing frequencies, depth of investigation is expected to decrease, emphasizing the near-borehole region. By including instrumentation for source orientation, azimuthal variations in properties can be determined. To date, all applications of orbital vibrators were directed towards fracture detection for the oil and gas industry (Cole et al, 1997a and 1997b).

Displacement Measurement: Underground instrumentation will concentrate on monitoring the movements of the discontinuities. A laser beam will be used to detect the ground movements. The laser will be located near the shaft, using the shaft as a reference point. Measuring points will be marked with a 3-ft long split set rock-bolt. Several reflectors will be used at curved drifts and stopes. The reflectors will be installed onto the split set. From the laser beam, a tape extensometer will be used to measure lateral ground movement. Therefore, the survey of convergence will be conducted from the absolute point near the shaft to the related points. This ground movement data will be correlated with the magnitude of seismicity to evaluate the characteristics of the rockburst and to enhance the understanding of the rockburst mechanism.

Spatial and Temporal Modeling: Geostatistical estimation and geologic structural modeling will be used to model stress fields as well as to identify the optimal orientation and spacing for the geosensing network. The influence of geologic structures will be defined and incorporated into a geostatistical analysis using solid body modeling software. Additionally, time series forecasting in conjunction with graphic animation will turn the data collected into practical information, thereby making possible prediction and identification of hazardously-high stress concentrations prior to structural failure.

Project Goals

The goals of the project are to study the spatial behavior of *in-situ* stresses associated with seismic events in the rock mass during mining in order to address the following questions: What is the source of the energy? Where is it stored? How is it released? A successful conclusion to this study will be the development of a cohesive approach to monitoring *in-situ* stresses. In practice, such a methodology will provide a means of actively mapping and forecasting potentially hazardous stress concentrations, thereby facilitating improved mining operations and safety.

Displacement Measurements and Spatial and Temporal Modeling: Over short periods of time, rocks behave elastically and transmit elastic (seismic) waves. The passage of these waves through the earth can be detected and analyzed to deduce details of the earth's structure and the mechanism that generates the waves. Many problems addressed through rock-mechanics studies are related to the failure of rock. Most failures radiate some energy in the form of seismic waves, making it possible to use a geosensing network to obtain information concerning the failures. Measurements of rockburst displacement need to be made within the fracture zone. Patterns of *in-situ* stress and rockburst magnitude can be correlated using seismic and geosensing networks. The information gathered by the two networks will be processed and summarized using time series and geostatistical modeling methods; the primary goal being the identification and mitigation of potentially hazardous stress concentrations and, subsequently, improved mine design and development procedures. This research will increase the understanding of the spatial nature and time- dynamic behavior of stress fields around active, hard rock mine structures, as well as developing experience leading to improved technology for *in-situ* stress measurement and geosensing.

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